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BIOLOGICAL CONTROL OF RHODESGRASS SCALE IN TEXAS BY NEODUSMETIA SANGWANI (RAO): Effectiveness and Colonization Studies

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SUMMARY

Investigations from 1961 to 1968 demonstrated the effectiveness of the parasite, *Neodusmetia sangwani* (Rao), as a controlling agent of rhodesgrass scale, *Antonina graminis* (Maskell). This internal parasite reduced scale populations 68.0 percent during the year. The two normal scale population peaks were reduced by 50 percent. The yearly mean parasitism varied from 28.1 to 34.6 percent. Parasitized scales produced 93.7 percent fewer crawlers on rhodesgrass and 90.1 percent fewer crawlers on paragrass. Ant control did not affect the effectiveness of the parasite under range conditions.

N. sangwani was successful in eliminating yield losses due to scale damage on a paspalum-fringed signalgrass site. This range control was substantiated with model experiments in greenhouses with rhodesgrass, fringed signalgrass, Texasgrass and cane sourgrass. Longevity studies at three biological control locations showed that rhodesgrass was not killed by scales even under severe grazing conditions.

Females of *N. sangwani* were found to have a short lifespan even under the most favorable conditions. Experiments showed that release of adults or distribution of parasitized scales (allowing adults to emerge) gave about equal results in establishment of colonies. The best month for release was August when 76.9 percent of the colonies became established. From 100 to 200 females were required per release site to insure 64 percent establishment.

Colony spread was found to occur at the rate of one-half mile per year in grasslands with normal scale populations. The female moved 6 feet or less by means of hopping and crawling in her life-time; however, wind transport was found to be important during periods of peak parasite activity in July-August and October. Females were caught at heights of 6 feet with sticky traps.

Techniques developed for distribution of *N. sangwani* on a large scale from naturally infested rhodesgrass scale were as follows. The grass was cut-off just below the ground with hoes and placed in boxes. The whole grass plant was then dropped from a pickup truck at points along predetermined lines. The potential number of parasites per stem was estimated by scale dissection. Release of one colony per mile was made, and colony spread and coalescence was evaluated in a pasture near Encino. The study showed that under the conditions of this test, 4 years would be required for the parasites to invade 83 percent of the range. The spread was restricted in saline areas which supported only *Spartina* sp., a plant that is not a host of rhodesgrass scale.

BIOLOGICAL CONTROL OF RHODESGRASS SCALE IN TEXAS BY NEODUSMETIA SANGWANI (RAO): Effectiveness and Colonization Studies

Michael F. Schuster and J. C. Boling*

The rhodesgrass scale, *Antonina graminis* (Maskell), was first found in Texas in 1942 attacking rhodesgrass, *Chloris gayana* Kunth (Chada and Wood 1960). Since that time this scale insect has been found infesting 94 species of grasses in North America (Chada and Wood 1960 and Schuster 1967). Introduction of the scale parasite, *Neodusmetia sangwani* (Rao), from India was made in 1959 (Dean, et al. 1961). Evaluation of the parasite as a control agent for rhodesgrass scale was begun in 1961. This paper summarizes control data and parasite-colony ecology under range conditions.

Previous Studies

Rhodesgrass scale was first described from grass at Hong Kong, China, as *Sphaerococcus graminis* (Maskell 1897). It was later described from India by Green (1908) as *Antonina indica*. The scale has been recorded from Africa, Australia, Brazil, Bermuda Islands, Canton Island, Ceylon, Colombia, Cuba, East Africa, El Salvador, Formosa, Guatemala, Hawaii, India, Japan, Johnston Island, Kwajalein (Marshalls), Madagascar, Mariana Islands, Puerto Rico, South China, Sumatra, United States, Venezuela and West Pakistan. The distribution within the United States was given by Chada and Wood (1960). These authors reported 62 counties infested by the scale in Texas. Areas in Texas known to be infested are shown in Figure 1.

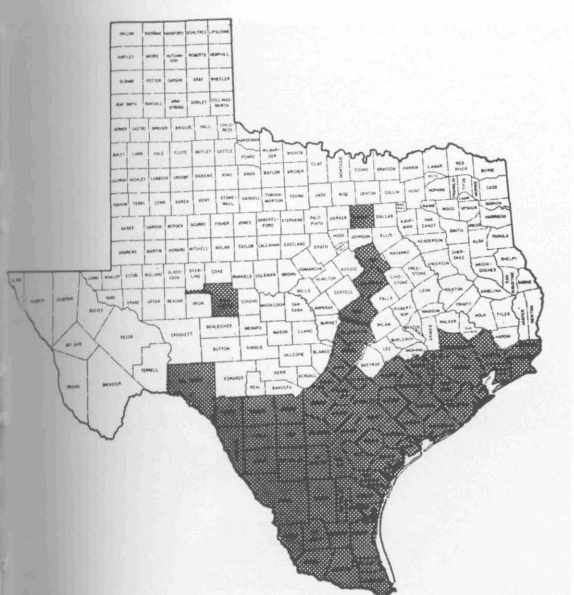

Figure 1. Areas infested by rhodesgrass scale in Texas.

The number of recorded hosts of the scale is increasing each year. Chada and Wood (1960) recorded 69 host species in the United States; Brimbelcrombe (1966), 14 in Australia; Guagliumi (1963), 22 in Venezuela; and Williams and Schuster (in press), 86 in Brazil. The large host range and wide distribution indicate that forage losses on ranges might be great under climatic conditions favorable for the scale. Chada and Wood (1960) reported that bermudagrass, *Cynodon dactylon* (L.) Pers., and rhodesgrass, *C. gayana,* were the only forage grasses affected by these scales in Texas. Schuster (1967) found that yields of 38 range grasses were significantly reduced by scales in greenhouse tests (Table 1).

Interviews with ranchers in Brooks, Kenedy, Willacy, Kleberg and Duval counties indicated that the grazing capacity of native ranges had been reduced approximately 30 percent since the introduction of rhodesgrass scale into Texas in the early 1940's. This heavy loss has not been regained, presumably due to scale infestation of native grasses.

The life history of the scale was described by Chada and Wood (1960). The adult scale is parthenogenetic and reproduces ovoviviparously. The crawlers are positively thigmotropic and attach themselves to the plant nodes under the leaf sheath. The legs are lost at molting and the second and third instar larvae are saclike and resemble the adult. There are five generations annually in southern Texas. About 85.4 percent of the scales are found below the first plant node on the crown node. Adults lived up to 6 weeks without food. Dissimination of individuals was mainly by crawling or wind.

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TABLE 1. REDUCTION IN YIELD AND PERCENT PLANT MORTALITY RESULTING FROM RHODESGRASS SCALE INFESTATION ON GRASSES IN A GREENHOUSE TEST[1]

Grass	Yield loss, percent	Plants killed, percent
Cane Sourgrass	26.1	42.1
Hybrid sourgrass	32.4	42.5
Longspike silver bluestem	28.5	23.6
Silver bluestem	18.2	85.0
Wright Threeawn	8.4	0.0
Red gramma	25.4	74.4
Fringed signalgrass	44.0	
Buffel sandbur	18.8	55.0
Coast sandbur	37.8	42.5
Big sandbur	10.2	52.0
Fringed windmillgrass	86.9	
Hooded windmillgrass	48.8	
Rhodesgrass	18.0	49.3
Nash windmillgrass	12.7	0.0
Shortspike windmillgrass	49.4	87.5
Bermudagrass	59.1	82.5
Arizona Cottontop (glabrous sp.)	88.3	85.0
Arizona Cottontop (pilos sp.)	28.6	0.0
Texas Cottontop	36.4	83.3
Plains lovegrass	36.4	0.0
Mourning lovegrass	17.4	0.0
Stinkgrass	20.1	0.0
Red lovegrass	28.7	6.2
Tumble lovegrass	48.7	65.6
Sand lovegrass	24.3	0.0
Green Sprangletop	29.0	55.0
Filly panicum	51.6	18.4
Halls panicgrass	34.7	26.5
Natalgrass	26.4	0.0
Knotroot bristlegrass	63.4	85.0
HBK bristlegrass	0.0	0.0
Southwestern bristlegrass	15.6	0.0
Texas bristlegrass	12.4	0.0
Hooked bristlegrass	18.6	90.3
Johnsongrass	38.0	0.0
Sand dropseed	29.1	0.0
Two flowered trichloris	20.6	17.5
Four flowered trichloris	32.4	0.0
Texasgrass	25.9	0.0

[1]From Schuster, 1967.

Early control measures were attempted with chemicals (Wene and Riherd 1950; Richardson 1953; Chada and Wood 1960); however, Chada and Wood (1960) pointed out that insecticides were too costly and are useless under range conditions.

Attempts to control the scale biologically were begun in 1949, when the parasite, *Anagyrus antoninae* Timberlake, was introduced from Hawaii (Riherd 1950). In 1954 and 1955 several parasites were introduced from France (Dean and Schuster 1958), but no establishment was obtained with *Xanthoencyrtus phragmitis* Ferr., *Boucekiella antoninae* (Ferr.), *Timberlakia europaea* (Mercet), and *Anagyrus diversicornis* Mercet. Dean and Schuster (1958) concluded that the effect of *A. antoninae* on rhodesgrass scale populations was of little value. The parasite was not able to withstand high temperatures and low humidities of Texas, except in certain ecologically modified areas around lakes and canals in the Lower Rio Grande Valley. The lowest parasite activity occurred during periods of highest scale populations.

The parasite, *N. sangwani*, was first found attacking rhodesgrass scale near Delhi and Bangalore, India by Narayanan, et al. (1957) and was originally described as *Dusmetia sangwani* by Rao (1957). Introduction and establishment of *N. sangwani* in Texas was made in 1959 (Dean, et al. 1961). Shipment of the parasite from India to the Insect Identification and Parasite Introduction Laboratories at Moorestown, N. J., was made by Rao (1965). Dean, et al. (1961) described the method of rearing the parasite for releases on range sites. Colonies established by Dean, et al. (1961) were the source of parasites introduced into Arizona, California, Bermuda Islands, Mexico and Brazil. Methods of laboratory rearing and distribution of individuals are described by Machado da Costa, et al. (in press).

Schuster (1965) studied the biology of the parasite under laboratory conditions. At 30° C, 17 to 20 days were required to complete a life cycle; at 20° C, 5 to 56 days were required. Later studies indicated that some individuals would complete a life cycle in 33 to 35 days at 20° C, indicating that 20° C is near the threshold temperature of arrested development. The pupal period was extended by low temperatures in the laboratory. Apparently the parasite overwinters as pupae near Delhi, India, in this manner (Narayanan, et al. 1957). Preimaginal stages included a caudate first instar, a hymenopteriform second instar, a similar but nonfeeding prepupa, and a pupa. Reproduction by unfertilized females resulted in male progeny. The short-lived brachypterous females laid an average of 6.2 eggs in each of 5.7 scales and produced an average of 35.3 offspring. The sex ratio of field-collected parasites ranged from 6.7 to 7.8 females to 1 male. The male has functional wings. Figure 2 shows a female ovipositing in a scale.

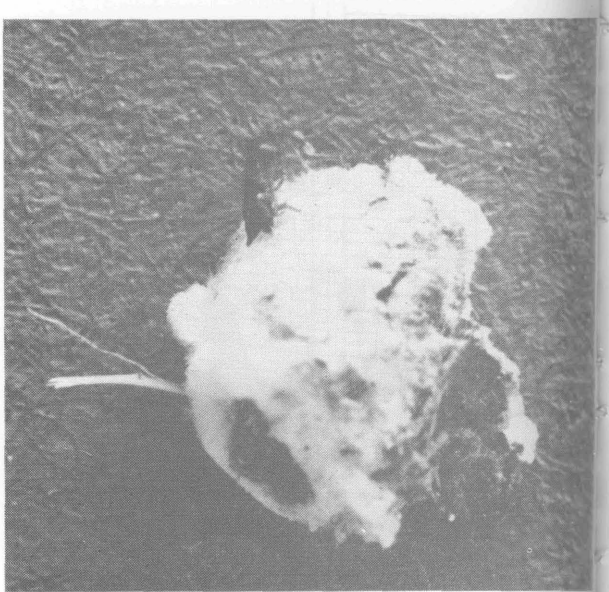

Figure 2. A parasite ovipositing in an adult rhodesgrass scale

The genus *Neodusmetia* was established with *N. sangwani* as the type species by Kerrich (1964). *Dusmetia indica* Burks (1957) is a synonym of *N. sangwani.*

When it was apparent in 1962 that *N. sangwani* was established and was giving apparent scale control, investigations were begun to establish parasite effectiveness and colonization techniques. The brachypterous condition of the female necessitated considerable effort for colony distribution. This paper describes (1) the effectiveness of *N. sangwani* as a population regulating agent; (2) control of scale damage due to this regulating effect in both laboratory and in range sites; (3) colonization techniques; and (4) colony spread under range conditions.

Procedures

The following locations were used in Texas as study areas: Kingsville, Armstrong, Brownsville, Encino, Mercedes, Rio Grande City, Weslaco and Donna. In addition, other study areas at San Antonio, La Pryor, Laredo and Three Rivers were sampled at irregular intervals. Eight different species of grass were sampled, including fringed signalgrass, *Brachiaria ciliatissima* Buckl.; fringed windmillgrass, *Chloris ciliata* Swartz.; rhodesgrass, *C. gayana;* bermudagrass, *C. dactylon*; johnsongrass, *Sorghum halepense* (L.) Pers.; paragrass, *Panicum purpurascens* Raddi; cane sourgrass, *Bothriochloa barbinodes* Lag.; and coast sandbur, *Cenchrus incertus* M. A. Curtis. Only one species was sampled at each location.

Grass culms for scale and parasite population determinations were selected monthly at random from the field and transported to the laboratory. Culms were stored in containers at 15° C until the scales could be removed. Scale populations and percent parasitism was determined on each plant species at each location. Different grass species had different growth periods and thus different scale developmental cycles were evaluated.

Scale populations were determined by counting all settled scale on selected nodes, usually the crown node. Only plants which had hardened culms were selected because scale crawlers settled on the more mature culms.

Parasitized scales were determined by dissection. The body contents of 100 third instar and/or adult scales were examined under magnification and percent parasitism recorded.

At various times 100 or more adult scales were isolated individually in 0.5-dram vials and held until crawler emergence stopped. The number of crawlers produced by both parasitized and nonparasitized scales was determined.

The effect of ants on the parasite was determined in a rhodesgrass pasture near Armstrong in 1961. Three randomized, 0.1-acre blocks were treated with 1 pound of heptachlor to kill ants, mainly *Crematogaster* and *Solenopis* sp. Twenty-five plants were selected from each plot, and the percent parasitism and number of scales per node was determined as previously described. Treatments were applied in April, and parasite and scale populations were determined in October.

The effect of parasite population-regulation on the yield of grasses was studied using container-grown grasses in model type experiments as well as on range sites. Model experiments were conducted with four grasses: rhodesgrass, fringed signalgrass, cane sourgrass and Texasgrass, *Vaseyochloa multinervosa* (Vasey) Hitchc. Each grass was planted in 5-gallon clay pots, and after seedling emergence, the pots were divided into 6 to 9 replicates of each treatment. The test treatments were (1) scale-free; (2) scale (adult rhodesgrass scale placed among the seedlings); and (3) biological control (same as 2 above but after scales became full-grown, 10 mated female *N. sangwani* per replicate were introduced). Scales on Texasgrass in the number 2 treatment were later exposed to parasites, and recovery of the grass was evaluated. Grass yields were taken by clipping all of the plants in each plot at flowering. Plants were clipped 5 inches above the soil, and yield was recorded as grams of ovendry hay. The average number of plants alive at the end of the experiment was recorded for rhodesgrass. Cane sourgrass did not have a number 1 treatment.

Range experiments were conducted in a transition paspalum-fringed signalgrass site previously described by Nord (1956) and Marrow (1959). Fringed signalgrass was the predominant species in this site. The first experiment in 1962 was conducted in cages 24 feet long and 6 feet wide made of 56 mesh saran material with zippers on one end for easy entrance (Figure 3). *N. sangwani* adults were introduced into one-half of the cages. Six months later, grass from six subsamples, 1 square meter, were clipped from within

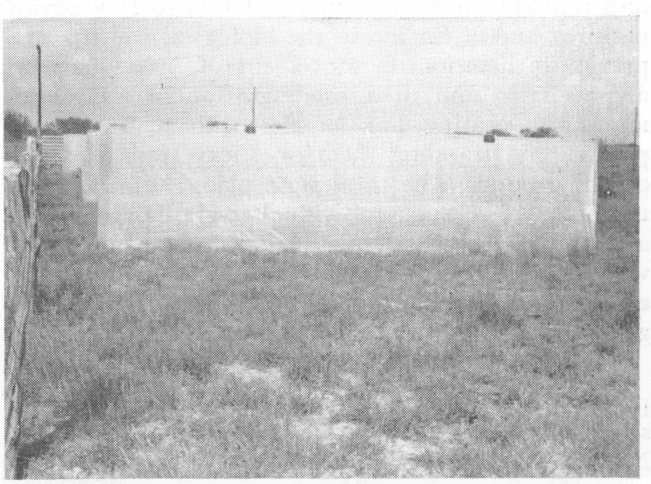

Figure 3. Cages used at Encino to confine *N. sangwani* in biological control studies.

each cage, and weights were recorded as grams of ovendry hay.

A second experiment was conducted in the same area, but the parasite release sample area was separated from a check area by a distance of 1.5 miles. Ten random 1-square meter samples were clipped in each area from 1963 through 1965. In 1965 the check area (no previous parasite releases) was infested with *N. sangwani,* and the areas were clipped during 1966 through 1968. Each month, data were collected on scales per node, percent nodes infested and percent parasitism.

From 1961 to 1965 rhodesgrass pastures were periodically observed for stand and stand persistence in Kleberg, Kenedy and Hidalgo counties. Other rhodesgrass pastures at distances of 2 to 3 miles were used for comparison after they had been infested with *N. sangwani.*

A limiting factor in any large scale distribution program with *N. sangwani* would be the short life of the female as pointed out by Schuster (1965). Therefore, means to increase longevity were explored. Female longevity studies were made by holding females at various temperatures and with various food supplements. Individuals were confined in groups of 10 in 50-cubic centimeter glass tubes closed with muslin held in place with a rubber band. Four to five replicates were made at 10, 15, 20, 25 and 30 degrees centigrade. Mortality was determined at the end of 24, 48, 72 and 124 hours. Food supplements in the form of 1 percent sucrose, royal jelly, honey, and 50 percent honey + 50 percent royal jelly were streaked on the inside of tubes, and parasite mortality determined at 20° C for the same time periods.

Mobility of individual parasites was determined by two methods. Aerial movement was sampled by use of 18-inch square sticky-traps coated with tanglefoot. Traps were positioned at various heights facing south (the prevailing wind direction). They were located at the Texas A&M University Agricultural Research and Extension Center at Weslaco just north of a railroad track, at Donna and Elsa in rhodesgrass pastures, and at Encino in the biological control area previously mentioned. Movement of individuals on a grass lawn and in a rhodesgrass field was determined by coating the females with a fluorescent powder and trapping them on sticky traps laid flat on the ground. The traps were placed upwind from the point of release. Individuals were detected with a lamp which radiated 3200 to 3800 angstroms ultraviolet light. A total of 1,500 females was released in each test. Individuals were also searched for in the grassmat with a portable ultra-violet lamp.

Colony dispersal was determined in rhodesgrass pastures at Kingsville, native grass pastures at Armstrong and Encino, along the highway, and along the Neuces River at Three Rivers.

Colony establishment on range lands as influenced by the number of female parasites and the time of year of release was investigated from 1961 to 1968. Parasites were reared in the insectary (Dean, et al. 1961) and released in multiples of 100 at points 2 or more miles apart. The dependency on natural scale populations for insectary rearing restricted the parasite release for the most part to the latter half of the year. Colony establishment was determined 1 year later.

Another phase of this study was a comparison of colony establishment by the release of female parasites versus the distribution of grass sprigs with parasitized scales attached. An estimate of the parasite population was made by dissection. An area near Encino was infested by each method with approximately 150 female parasites during August 1966. The release sites were alternated at 0.5-mile intervals until 50 sites had been infested by each technique. Attempts at colony detection were made every 3 to 4 months following release. These data indicated the investigator's ability to detect colonies with passage of time. Scales were examined by a "thumbnail test". Third instar and second adult scale were mashed between the thumb and index finger. The contents were observed with a 10 power hand lens. Scales were examined until one was found to be parasitized or until 50 scales selected randomly had been examined.

Procedures for mass distribution of the parasite on range sites were determined on a 43-square mile pasture near Encino. Rhodesgrass sprigs with a natural infestation of scales and parasites collected from a pasture were distributed at 1-mile intervals from a pickup truck in October 1962. The number of parasites per release point was estimated beforehand by determining the average number of parasites per scale and the average number of third instar and adult scale per culm. Ten culms which yielded approximately 100 female parasites were dropped at each point. Releases were made at only 40 points due to the rough terrain.

Colony establishment and colony coalescence were determined at 6-month intervals, beginning 12 months after release date. Transect samples were made at 0.5-mile intervals along predetermined lines. Parasites were detected by the thumbnail test described above. The same sample points were examined on subsequent dates to estimate colony movement.

Results

Population Regulation of Rhodesgrass Scale

The percent parasitization of rhodesgrass scale varied considerably throughout the year (Figure 4). Yearly average parasitism from 1961 to 1965 varied from 28.1 to 34.6 percent. Monthly means varied from 23.3 to 37.8 percent. Parasitization of scales increased after April and remained at a high level throughout the summer and fall. Percent parasitization was lower during periods of rapid scale increase, due to preference by the adult parasite not to oviposit in the

TABLE 2. POPULATION REGULATION OF RHODESGRASS SCALE AND PERCENT PARASITIZATION BY *N. SANGWANI* ON RANGE SITES IN SOUTH TEXAS DURING 1963 TO 1965

Location	Grass sampled	Samples	Scale/node		Nodes/infested, %		Scale[1]
			Bio-control	Check	Bio-control	Check	Parasitized, %
Kleberg Co.	Rhodesgrass	17	1.54	3.85	41.5	59.3	45.7
Hidalgo Co.	Paragrass	5	1.69	7.29			22.0
Kenedy Co.	Rhodesgrass	15	1.09	3.61	30.6	59.1	32.2
Brooks Co.	Signalgrass	23	.91	1.92	26.6	42.1	30.9
Avg % reduction[2]			68.6		39.1		

[1]Third instar and adult scale.
[2]Reduction of scale numbers in bio-control compared to check (no parasites released).

first two instars of the scale. At these times the scale population consisted almost exclusively of the first two instars, and a lag occurred in parasitization until the scale became acceptable for oviposition by the parasite.

Peaks in scale numbers occurred in June and November in the normal population (Figure 4). Reduction of rhodesgrass scale in parasite-regulated areas was greatest during periods of peak scale numbers but less in periods of fewer scale numbers. During the summer, high temperatures killed large numbers of scales. In the parasite-regulated population, the June peak of scales occurred normally, but the November peak was delayed. However, about 50.0 percent fewer scales occurred at both peaks in parasite-regulated populations. The rate of increase of scales in parasite-regulated populations was less than nonregulated populations.

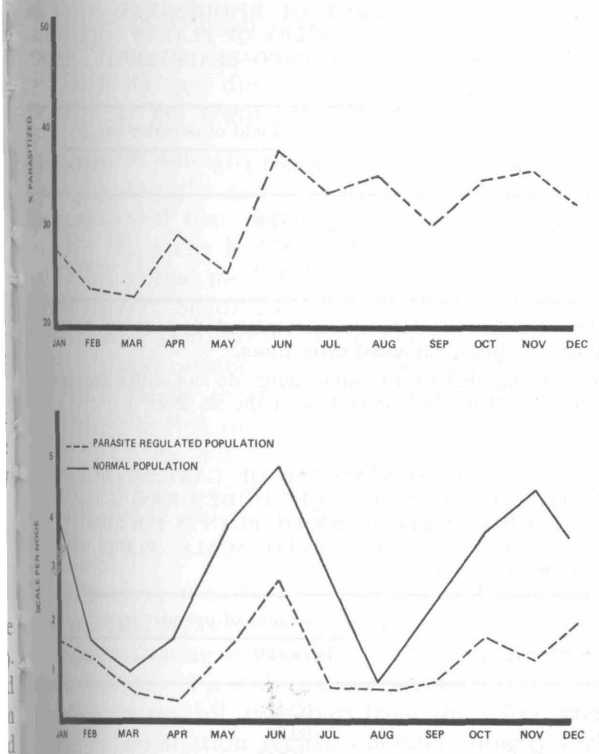

Figure 4. Average percent third instar and adult scale parasitized (upper figure) and average rhodesgrass scale numbers in a normal and parasite-regulated population (lower figure) during 1961-65 in South Texas at nine locations, on seven grass species.

The data in Table 2 show scales per node, percent nodes infested and percent parasitized scales from four representative locations. The average reduction of scales was 68.6 percent while the reduction of percent nodes infested was 39.1 percent. As scale populations decreased, the survivors were found mostly in niches under leaf sheaths or on the underground culms. The searching ability of the female parasite may be limited in these areas. Therefore, some nodes were always infested, although the general population was low.

It is evident from the data in Tables 2 and 9 that a percent parasitization figure is of little value in evaluating the population-regulating ability of *N. sangwani*. The number of scales per node demonstrates regulating ability better than percent nodes infested or percent scales parasitized.

The scale population in parasite-regulated populations increased at a slower rate during both the April and September periods of scale increase. The reduced fecundity by parasitized scales probably contributed greatly to this delay (Table 3). Parasitized scales produced 93.7 and 90.1 percent fewer crawlers on rhodesgrass and paragrass, respectively, than on-

TABLE 3. AVERAGE NUMBERS OF RHODESGRASS SCALE CRAWLERS PRODUCED BY PARASITIZED AND NON-PARASITIZED SCALE

Host grass	Avg number of crawlers	
	parasitized	not parasitized
1963		
Rhodesgras	7.7	107.5
1964		
Rhodesgrass	3.3	43.9
Paragrass	.0	26.7
1965		
Rhodesgrass	1.8	89.4
Paragrass	6.7	56.8
1967		
Rhodesgrass	6.4	63.6
Paragrass	5.6	41.0
Average		
Rhodesgrass	4.8	76.1
Paragrass	4.1	41.5

TABLE 4. EFFECT OF ANT CONTROL ON RHODESGRASS SCALE NUMBERS AND PARASITISM BY *N. SANGWANI* IN A RHODESGRASS PASTURE NEAR ARMSTRONG

	Ant control	Check
Parasitism, %	52.6	44.6
Parasites per scale	8.8	8.1
Scale per node	1.3	1.4
Nodes infested, %	46.7	56.7

parasitized scales. The full production of crawlers probably was not realized since scales were removed from the plant; although, Chada and Wood (1960) found that scales would live 6 weeks without food. Greater numbers of crawlers were produced by scales collected from rhodesgrass than from paragrass. This indicates that rhodesgrass is a more acceptable host than paragrass and may further indicate that other grass species might have different reproductive effects on the scale. Limited samples made in the same manner with johnsongrass and fringed signalgrass indicated that they were as acceptable as rhodesgrass.

Ant Control and Parasite Activity

The data in Table 4 indicate that little or no benefit could be obtained from ant control. Schuster (1965) found that adult *N. sangwani* did not feed on the scales and that the oviposition act was short. Flanders (1963) pointed out that host feeding by the female parasite is a prerequisite for ant-induced outbreaks of scale insects that are controlled by hymenopterous parasites. Also, Bartlett (1961) has shown that length of the oviposition act by the adult hymenopterous parasite increases its susceptibility to ant disturbance during egg deposition if easily disturbed by nearby objects. This experiment indicates that effectiveness of *N. sangwani* is little influenced by native ants.

Scale Control and Yield Response

Model experiments were conducted to obtain detailed information in scale control and subsequent yield increase of four grass species. Rhodesgrass data are shown in model experiment 1 (Table 5). There was no significant difference in yield or plant stand for the bio-control treatment and the scale-free treatment. Scales significantly reduced yield and plant stand in the absence of parasites.

TABLE 5. YIELD RESPONSE AND SURVIVAL OF RHODESGRASS AS AFFECTED BY CONTROL OF RHODESGRASS SCALE BY *N. SANGWANI,* MODEL EXPERIMENT 1[1]

Treatment	Total yield of ovendry hay, g	Plants alive at end of test
Bio-control	560.5 a[2]	5.14 a[2]
Scale	454.2 b	1.57 b
Scale free	632.5 a	5.14 a

[1]Fifteen clippings over a 2-year period.

[2]Means bounded by the same letter do not differ at the .05 level according to Duncan's Multiple Range Test.

TABLE 6. YIELD RESPONSE OF FRINGED SIGNALGRASS AS AFFECTED BY CONTROL OF RHODESGRASS SCALE BY *N. SANGWANI,* MODEL EXPERIMENT 2. (FOUR CLIPPINGS)

Treatment	Yield of ovendry hay, g
Bio-control	55.85 a[1]
Scale	30.85 b
Scale free	58.03 a

[1]Means bounded by the same letter do not differ according to Duncan's Multiple Range Test at the .05 level.

Fringed signalgrass responded to the above treatments in the same manner as rhodesgrass (Table 6). There was no difference between the biological control and scale-free treatments, and both had greater yield than the scale treatment.

Texasgrass treated as above reacted like the two previously mentioned plant species (Table 7). After parasites were introduced into the scale treatment plots, there was no difference between the treatments. There appeared to be an increase in yield in the bio-control and scale-delayed, parasite-release plots compared to scale-free plots. The yield was slightly, although not significantly, greater than the scale-free.

TABLE 7. YIELD RESPONSE OF TEXASGRASS AS AFFECTED BY CONTROL OF RHODESGRASS SCALE BY *N. SANGWANI* AND RECOVERY OF PLANTS FOLLOWING RELEASE OF PARASITES INTO SCALE PLOTS, MODEL EXPERIMENT 3

Treatment	Yield of ovendry hay, g[1]	
	Period 1	Period 2
Bio-control	39.77 a[2]	48.21 a
Scale	27.65 b	47.91 a
Scale free	44.61 a	43.68 a

[1]Period 1 harvested four times; period 2, parasites introduced into scale plots, harvested three times.

[2]Means bounded by the same letter do not differ according to Duncan's Multiple Range Test at the .05 level.

TABLE 8. YIELD RESPONSE OF CANE SOURGRASS AS AFFECTED BY CONTROL OF RHODESGRASS SCALE WITH *N. SANGWANI;* RECOVERY OF PLANTS FOLLOWING RELEASE OF PARASITES INTO SCALE PLOTS, MODEL EXPERIMENT 4

Treatment	Yield of ovendry hay, g[1]	
	Period 1	Period 2
Scale	62.17	129.29
Scale free	80.93	126.26
t, p = .95	2.74*	1.05 ns

[1]Period 1 – clipped two times after scale infestation in February; period 2 – parasites introduced into scale plots in May and clipped four times, July through December.

TABLE 9. COMPARISON OF RHODESGRASS SCALE REGULATION AND FORAGE YIELD OF A PASPALUM-FRINGED SIGNALGRASS RANGE SITE NEAR ENCINO BEFORE AND AFTER THE CHECK AREA WAS INFESTED WITH *N. SANGWANI*

Period of study	Scale/node, %		Nodes infested, %		Parasitism, %		Yields (lb./acre)		t, p = .95
	Bio-control	Check	Bio-control	Check	Bio-control	Check	Bio-control	Check	
				Prior to check being infested with *N. sangwani*					
1963-65	.91	1.91	26.6	42.1	30.9	0	1850.7	1021.2	10.39**
				After check infested with *N. sangwani*					
1966-68	.59	.66	27.0	26.9	24.1	14.0	2117.0	2262.0	.93 ns

treatment during period 2. Since the treatments were fertilized equally, disregarding treatment, it is probable that as the parasite achieved control, the residual fertilizer in the pots was utilized by the plants and greater yield resulted.

Model experiment 4 shows that cane sourgrass can recover rapidly after the scale is controlled by *N. sangwani* (Table 8). The scale treatment plots recovered rapidly after scales were controlled and yielded a slightly, but not significantly, greater yield than the scale-free treatment plots.

Control Experiments on Ranges

N. sangwani reduced rhodesgrass scale populations in screened cages by 50 percent within 3 months. A single clipping 3 months later showed that parasite-infested cages yielded 511.3 pounds of airdry hay while the control cages (no parasites) yielded 145.9 pounds of airdry hay.

Grasses died in all cages about 7 months after caging. This was apparently the result of reduced light inside the cage due to color change in the saran covering. At the beginning of the test, the screen cover reduced sunlight within the cage 10 percent. About the time the grass began to die, light meter readings showed that sunlight had been reduced 60 percent. The saran had darkened considerably and had shrunk so that mesh size was smaller than at the start of the test. Shading also allowed the scale population to increase to greater numbers than those normally on plants outside the cages. Scales on the outside had a greater mortality because of lethal high temperatures during the summer, as has been demonstrated by Chada and Wood (1960). Fringed signalgrass apparently is greatly affected by shading as it does not occur under the shade of mesquite trees (*Prosopis* sp.)

Comparison of biological control areas with check areas (without parasites) proved to be the best method of demonstrating scale control. The first 3 years of clipping showed a 44.2 percent greater yield from the biological control area than from the check area (Table 9). Population regulation data showed that scale had been reduced 52.6 percent, with an average parasitization of 73.9 percent (Table 9). Following release of *N. sangwani* into the check area in 1965, only a slight difference in yield was found between biological control and check plots for the next 3 years of clipping. Similarly, slightly greater yields were obtained in check areas than in biological control areas as was found in Texasgrass and cane sourgrass model experiments (Tables 7 and 8).

Rhodesgrass Pasture Longevity

Chada and Wood (1960) stated that when rhodesgrass infested with rhodesgrass scale were grazed they died within 3 years. Similar observations were recorded in Queensland, Australia, and fertilization and controlled grazing were recommended to restore vigor (Anon. 1940).

In general, pure grass stands were conducive to wide fluctuations of scale populations. As scale populations increased, severely damaged culms died, and new culms were produced. Finally the entire plant died. At certain times greater scale numbers were found on grass in the biological control area when compared to the check area. This resulted indirectly since scale control by the parasite resulted in more robust plants and greater areas on the plants for scale development. But parasite activity soon reduced scale peaks. The average scale populations for the Kleberg and Kenedy county test areas are shown in Table 2. In all cases, plants in the check areas began to show considerable damage by the end of the second year and were dead at the end of the third year. Plants in the bio-control areas were still alive and producing good yields at the end of 5 years when observations stopped.

Female N. sangwani Longevity

The number of female parasites surviving for 24 hours at 10, 15, 20 and 30 degrees centigrade was 50.7, 40.7, 43.2 and 40.9 percent respectively (Table 10). Survival of females was best at 10° C, at which 41.3 percent survived for 48 hours. Since summer

TABLE 10. THE INFLUENCE OF TEMPERATURE ON THE LONGEVITY OF FEMALE *N. SANGWANI*

Temperature °C	Percent alive at end of time indicated in hr.				
	24	48	72	96	124
10	50.7	41.3	16.0	0	
15	40.7	29.6	9.3	7.4	3.7
20	43.2	18.5	1.0	0	
30	40.9	0			

TABLE 11. NUMBER OF FEMALE *N. SANGWANI* CAUGHT AT TWO HEIGHTS ON 18-INCH SQUARE TANGLEFOOT TRAPS, 1965

	Females caught on trap			
	Weslaco		Donna	
Period	3 ft	4 ft	3 ft	Total
June 4-21	0	0	0	0
July 2-30	11	0	0	11
Aug 6-27	3	0	0	3
Sept 3-24	3	1	0	4
Oct 1-25	0	9	1	10
Nov 12-26	0	1	0	1
Dec 3-17	0	0	0	0
Total	17	11	1	29

temperatures reach 35° to 40° C on Texas ranges, the life of the female parasite must be very short under range conditions. There was only slight mobility of the female at 15° C and none at 10° C.

Feeding studies with 1 percent sucrose, royal jelly, honey and 50 percent royal jelly to 50 percent honey at 20° C showed no increased parasite survival over the nonfeeding check insects at 24, 48 and 72 hours. Neither food supplements nor temperature modification appeared to be practical in reducing parasite mortality sufficiently for a mass distribution program.

Mobility of N. sangwani Females

Weekly inspection of sticky traps showed that females were caught at 3 and 4 feet above the ground during 1965 (Table 11). During 1966 females were caught 6 feet above the ground (Table 12). Parasites were caught in greatest numbers during July and August, with a lesser peak in October. These peaks coincide with periods of greatest parasitism of scales by *N. sangwani*.

Rhodesgrass plants support 2 to 4 times greater scale numbers than most grasses. Assuming that an equal percentage of scales were parasitized during a period of time, it can be seen that rhodesgrass pastures would produce greater numbers of individual parasites; hence, greater numbers were trapped in a rhodesgrass pasture at Elsa. Equal size plates, placed on the ground during the same period of time in August, often trapped 150 to 200 individuals.

Females coated with fluorescent powder and released in a lawn were found trapped 2 days later on the sticky traps at distances up to 6 feet from point of release. This lawn grass was 2 inches in height and was almost free of rhodesgrass scale. The test was repeated in a rhodesgrass pasture which averaged six scales per node and 65 percent parasitization. None of the 1,500 females marked and released was recovered although several hundred unmarked parasites were captured on the traps. Apparently females on the rhodesgrass did not have to search as actively because of the existing scale population and thus failed to reach the traps.

Activity of marked females was closely observed with the aid of ultra-violet light. Females released at the grass crown moved rapidly upward in search of suitable scales. Females were found at the apex (1 meter high) of rhodesgrass plants within a few minutes of release; then individuals reversed the searching pattern and proceeded down the plant. Active hopping by the female was infrequent and appeared to be an avoidance reaction. Wind caused some females to become dislodged from plants.

These data suggest that wind dispersion of the brachypterous female may be greater than by crawling and hopping. The greatest colony increase was during the summer months and airborne movement was greatest in grasslands with large scale populations.

Colony Spread in Grasslands

At Armstrong, *N. sangwani* colony spread was at the rate of about one-half mile per year in a pasture of rhodesgrass and sandburgrass. However, the spread through a saline area in which *Spartina* sp. (a nonhost species) was growing was less than one-half mile in 4 years and in the direction with the prevailing wind. At Encino in a paspalum-fringed signalgrass site, the parasite spread 0.4 miles each year for 3 years. Near Three Rivers, colony spread in bermudagrass and sandburgrass along a highway was about one-half mile each year for 3 years; however, the parasite was found 21 miles downstream on the Neuces

TABLE 12. FEMALE *N. SANGWANI* CAUGHT ON 18-INCH SQUARE STICKY TRAPS AT VARIOUS HEIGHTS FROM FOUR LOCATIONS IN SOUTH TEXAS, 1966

	Weslaco			Donna			Encino			Elsa			
Period	1 ft	3 ft	6 ft	1 ft	3 ft	6 ft	1 ft	3 ft	6 ft	1 ft	3 ft	6 ft	Total
Jan 1-July 1	0	0	0	0	0	0	0	0	0	0	0	0	0
July 4-27	0	0	0	0	0	0	0	1	0	5	0	2	8
Aug 2-29	0	0	0	0	0	0	2	0	0	2	1	0	5
Sept 6-27	0	0	0	1	0	0	0	0	0	0	0	0	1
Oct 7-24	0	0	0	0	0	0	0	0	0	5	2	0	7
Nov 1-14	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov 14-Dec 31	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	1	0	0	2	1	0	12	3	2	21

River in the same period of time. Apparently, flooding washed grass clones with scales and parasites down the river channel. Thus, parasite spread downstream may be an important means of distribution. In a rhodesgrass pasture near Kingsville the rate of spread was one-third mile per year for 2½ years. These observations indicate that colony spread is greatest in grasslands which provide the most contiguous scale populations.

Colony Establishment as Influenced by Number of Females Released And Month of Release

The data in Table 13 show that as the number of females released per site increased, the percentage of colony establishment increased; however, 100 percent establishment was never attained. The release of 100 to 200 females established colonies 64 percent of the time. The best month for release was August, when 76.9 percent of the colonies were established. The poorest time was the November-December period when 35.7 percent of the released colonies became established. An average of 53.4 percent of the total colonies released became established.

Range sites for release of parasites were chosen without regard to vegetation, scale population, temperature and precipitation. These factors obviously contributed to low colony establishment in the above tests. Parasites were collected each morning between 7 and 9 a.m. and delivery time to range sites varied from 1 to 8 hours. Many females were probably unable to oviposit before death. These factors would be encountered in any large-scale release program. Dispersal of adults does not appear practical unless individuals can be collected periodically during the day and released quickly.

TABLE 13. COLONY ESTABLISHMENT AS INFLUENCED BY NUMBERS OF FEMALE *N. SANGWANI* AND PERIOD OF RELEASE ON RANGE SITES IN SOUTH TEXAS

No. of females released per release point, range	Colony establishment, %
0 - 100	41.8
100 - 200	64.0
200 +	90.0
over-all average (133 points)	53.4

Mo of release	Colony establishment %
Aug	76.9
Sept	66.7
Oct	53.1
Nov-Dec	35.7
Over-all average (126 points)	51.6

TABLE 14. COLONY ESTABLISHMENT OF *N. SANGWANI* FOLLOWING RELEASE OF 150 FEMALES OR PREIMAGINAL STAGES ON RANGE SITES AND FREQUENCY OF COLONY DETECTION FOLLOWING RELEASE IN AUGUST, 1966, ENCINO

Sample date (interval)	Established colonies detected, %	
	preimaginal	adult
November 2, 1966 (3 mo)	21.7	18.2
January 12, 1967 5 mo)	39.1	31.8
May 19, 1967 (9 mo)	47.8	50.0

N. sangwani Colony Establishment as Influenced by Life Stages of Parasites At Time of Release

The data in Table 14 show that there were only slight differences in the number of established colonies resulting from the release of adults or preimaginal stages while still within rhodesgrass scale. There was a definite increase in the number of colonies detected with time. The results of this test did not differ greatly from data on the number of sites established in the above test.

The results indicate that the distribution of parasites, while still within the scale bodies, would be as effective as the release of adults. Furthermore, the expense would be far less than if a laboratory culture had to be maintained to produce the adult numbers required for mass distribution. Also, the problem of the short life of the female parasite would be overcome as the parasite would be transported in the relative hearty preimaginal stage and emergence of the adult would be under more natural conditions.

Large Area Distribution

A test was conducted in October, 1963, to determine procedures and approximate cost involved in collecting and distributing parasites from a natural population. Scales and parasites were collected from a rhodesgrass pasture near Armstrong by cutting off the grass just below the ground with a hoe and transporting the vegetation in boxes to desired release sites. Previous dissections indicated that 10 stems would be required at each release point to produce 100 female parasites. It required 16 hours of labor and 124 miles of driving with a ¾-ton truck to infest the 43-square mile pasture. The cost was about $1.28 per square mile. Grass stems ready for distribution are shown in Figure 5.

Colony Coalescence

The frequency of colony encounter for periods of time following release near Encino are shown in Table 15. There was a rapid increase in colony encounter for the first 2 years. Thereafter, the frequency of encounter increased slowly and at the end of 4½ years 83 percent of the sample sites were invaded by the parasite. About 10 percent of the sample sites were in saline areas, predominated by *Spar-*

Figure 5. Grass stems separated and prepared for distribution to release points as described in the text. Parasites will emerge from scale on the grass and oviposit in scale at the release site.

tina sp.; this accounted for the incomplete parasite coverage of the area.

The data indicated that 4 or more years may be required for complete coverage of ranges where *N. sangwani* were released at a density of one colony per square mile. Greater scale numbers and a more contiguous scale population through the year would probably reduce the time required for complete coverage.

Discussion

This is believed to be the first successful introduction of a predator or parasite for the control of an insect attacking grass plants on ranges. The biological control of insects attacking the low value grasslands offers opportunities in biological control that are not fully realized. As yet there is little quantitative information on the damage done by insects under normal or outbreak conditions. Sparse attention has been paid to the damage of grasshoppers (Anon. 1962). App (1962) discussed various direct and indirect results of insect attack on pastures, and Anderson (1961) evaluated losses caused by grasshoppers on grasslands. It is possible that range ecologists are not fully cognizant of the damage to rangelands resulting from insects; hence, little effort has been directed toward their control.

Grasslands provide a relative stable environment for the operation of biological control organisms. Lloyd (1960) suggested that biological agents have been successful mainly where host plants are trees or other perennials maintaining their geographical locations over long periods of time. Turnbull and Chant (1961), however, questioned Lloyd's hypothesis and proposed that suitability for biological agents was determined by the type of damage inflicted by an insect, the amount of such damage that can be tolerated and pest population density required to produce intolerable damage. In general, perennials can withstand certain types of damage, such as defoliation, better than annuals. The amount of damage to grasslands can only be measured as pounds of grass harvested from the final animal end-product, such as meat or wool. Thus, the category of *direct pests*, as they proposed, does not exist in grasslands. The definition, *which by directly attacking produce, destroy a significant part of its value,* cannot occur in grasslands, for even a blade of grass 20 percent eaten by a caterpiller still retains 80 percent feeding value to the animal.

The low value of grasslands also increases the attractive atmosphere for the utilization of biological agents. Rhodesgrass scale fitted the category of an indirect pest which required large numbers over a protracted period of time to cause damage. Chemical control was economically feasible only on lawns and golf greens. Clearly, it lent itself well for biological control effort.

The rapid control experienced with *Neodusmetia sangwani,* while several other parasites failed to establish themselves even with repeated introductions, supports Clausen's (1951) view that a fully effective parasite or predator is always easily and quickly established and thus control is usual in three host generations, or 3 years. Substantial host reductions were obtained in the first year.

TABLE 15. FREQUENCY OF *N. SANGWANI* COLONY ENCOUNTER AS DETERMINED BY LINE TRANSECT SAMPLING OF AN AREA NEAR ENCINO RELEASED AT A DENSITY OF ONE COLONY PER SQUARE MILE, OCTOBER 1962

Time from release, mo	12	21	23	29	31	39	43	47[1]	56
Colony frequency,%	4	20	33	40	52	62	68	76	83

[1]Based on incomplete sample.

N. sangwani reduced its host primarily by preventing reproduction of its parasitized host. The percent reduction of total scale population was always greater than the percent parasitism. For this reason, percentage parasitism as an index of scale control is misleading. Yield comparison between treatments was the most indicative, and laboratory data proved as good as field data.

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